

AXIAL FAN BLADE WITH WAVY AIRFOIL AND TRAILING EDGE SERRATIONS

BACKGROUND

[0001] This disclosure relates generally to air conditioning systems and, more particularly, to a fan adapted for use in an air conditioning system to provide a sound benefit over conventional systems.

[0002] In fans or similar devices, the rotation of one or more blades through a gaseous medium, e.g., air, creates a flow of the medium, sometimes giving rise to audible noise. Noise that occurs during fan operation can be generated by mechanical components, such as motors and bearing, or by aeroacoustic mechanisms. For the aeroacoustic process, unsteady flow along each blade element may cause pressure variations that interact with the blades to generate noise. Several factors affect the aeroacoustic generation mechanism, including but not limited to the geometry of the blade edges, the number of blades, etc.

SUMMARY

[0003] According to an embodiment, an axial flow fan includes a hub rotatable about a fan axis and a plurality of fan blades mounted to the hub. One of the plurality of fan blades includes at least one wave extending in a span wise direction over the fan blade and at least one serration extending along a trailing edge of the fan blade. The at least one wave and the at least one serration are arranged at a location between 40% and 100% of a span of the fan blade.

[0004] In addition to one or more of the features described above, or as an alternative, in further embodiments the at least one wave is positioned adjacent a trailing edge of the fan blade.

[0005] In addition to one or more of the features described above, or as an alternative, in further embodiments the at least one wave is arranged between 30% -100% of the chord as measured from a leading edge of the fan blade.

[0006] In addition to one or more of the features described above, or as an alternative, in further embodiments the at least one serration is formed in a chord of the fan blade.

[0007] In addition to one or more of the features described above, or as an alternative, in further embodiments a height of the at least one serration has is equal to between 0% and 30% of a chord length of the fan blade.

[0008] In addition to one or more of the features described above, or as an alternative, in further embodiments a contour of the at least one wave is generally smooth.

[0009] In addition to one or more of the features described above, or as an alternative, in further embodiments a contour of the at least one wave is generally sharp.

[0010] In addition to one or more of the features described above, or as an alternative, in further embodiments the at least one wave includes a plurality of waves.

[0011] In addition to one or more of the features described above, or as an alternative, in further embodiments the plurality of waves includes between two waves and six waves.

[0012] In addition to one or more of the features described above, or as an alternative, in further embodiments a contour of the at least one serration is generally smooth.

[0013] In addition to one or more of the features described above, or as an alternative, in further embodiments a contour of the at least one serration is generally sharp.

[0014] In addition to one or more of the features described above, or as an alternative, in further embodiments the at least one serration includes a plurality of serrations.

[0015] In addition to one or more of the features described above, or as an alternative, in further embodiments the plurality of waves includes between two serrations and six serrations.

[0016] In addition to one or more of the features described above, or as an alternative, in further embodiments the at least one wave is equal in number to the at least one serration.

[0017] In addition to one or more of the features described above, or as an alternative, in further embodiments a cross-section of the fan blade has a profiled airfoil shape.

[0018] In addition to one or more of the features described above, or as an alternative, in further embodiments the fan blade has a sweep.

[0019] In addition to one or more of the features described above, or as an alternative, in further embodiments comprising a shroud coupled to a tip end of each of the plurality of fan blades such that the shroud is rotatable about the fan axis.

[0020] In addition to one or more of the features described above, or as an alternative, in further embodiments the axial flow fan is formed from a plastic material via an injection molding process.

[0021] In addition to one or more of the features described above, or as an alternative, in further embodiments an amplitude of the one or more waves as measured along the axial dimension is larger at the trailing edge than at the leading edge.

[0022] In addition to one or more of the features described above, or as an alternative, in further embodiments an amplitude of the one or more waves as measured along the axial dimension varies continuously from the trailing edge than at the leading edge.

[0023] According to another embodiment, an axial flow fan includes a hub rotatable about a fan axis, a plurality of fan blades mounted to the hub, and a shroud mounted to a tip end of each of the plurality of fan blades. Each of the plurality of fan blades includes three waves extending in a span wise direction over the fan blade. The three waves are positioned adjacent a trailing edge of the fan blade between 40% and 100% of a span of the fan blade. Each of the plurality of fan blades includes three serrations extending in a chord wise direction over the fan blade. The three serrations are positioned adjacent a trailing edge of the fan blade between 40% and 100% of a span of the fan blade.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The subject matter, which is regarded as the present disclosure, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the present disclosure are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0025] FIG. 1 is a perspective view of an example of an coil unit according to an embodiment;

[0026] FIG. 2 is a perspective view of a fan of the coil unit of FIG. 1 according to an embodiment;

[0027] FIG. 3 is a plan view of a portion of the fan of FIG. 2 according to an embodiment;

[0028] FIG. 4 is a cross-section of a fan blade according to an embodiment;

[0029] FIG. 5 is a perspective view of a portion of a fan blade according to an embodiment;

[0030] FIG. 6 is a root end view of a fan blade according to an embodiment;

[0031] FIG. 7 is a plan view of a fan blade including a plurality of serrations according to an embodiment;

[0032] FIG. 7A is a cross-sectional overlapping view of the sections AA, BB, And CC, of FIG. 7 according to an embodiment;

[0033] FIG. 7B is a cross-sectional view of each of sections AA, BB, And CC, of FIG. 7 according to an embodiment; and

[0034] FIG. 8 is an axial view of a fan blade according to an embodiment.

[0035] The detailed description explains embodiments of the present disclosure, together with advantages and features, by way of example with reference to the drawings.

DETAILED DESCRIPTION

[0036] Referring now to FIG. 1, an example of a coil unit 20 of an HVAC system is illustrated. The coil unit 20 includes a heat exchanger 22 where the planform is a generally square structure, although embodiments where the planform of the heat exchanger 22 is rectangular, cylindrical, or another shape are also within the scope of the disclosure. A compressor 24, fluidly coupled to the heat exchanger 22 is positioned within the interior of the heat exchanger 22 and is configured to compress refrigerant through a vapor compression cycle. Disposed in contact with a surface of the heat exchanger 22 is a fan 26 configured to draw ambient air radially inward, through the heat exchanger 22, after which the warmer air is discharged upwardly through an opening 28.

[0037] A fan 26 having a reduced noise signature is illustrated in FIGS. 2-4 in more detail. Although the fan 26 is illustrated and described with reference to the coil unit 20, it should be understood that the fan 26 may be suitable for use in other air conditioning applications. The fan 26 is an axial flow fan and includes a hub 30 having a plurality of fan blades 32 mounted thereto. The plurality of fan blades 32 is generally equidistantly spaced about an outer periphery of the hub 30 and extends radially outwardly therefrom. In an embodiment, the distal ends of the fan blades 32 are connected to a shroud or casing 34, as shown in FIG. 2, such that the shroud 34 is rotatable with the fan blades 32. However, embodiments where the fan 26 does not include a shroud, or where the shroud is stationary relative to the fan blades 32 are also within the scope of the disclosure. The hub 30, fan blades 32, and shroud 34 when included, may be separate components coupled together, or alternatively may be integrally formed, such as from an injection molded plastic for example.

[0038] In the illustrated non-limiting embodiment, the fan 26 comprises an axial flow fan rotatable about an axis of rotation X. A motor, illustrated schematically at M, operably connected to the fan 26, e.g., via a shaft or another coupling means, such as a belt, rope, or chain, may be used to rotate the fan about the fan axis X in a direction indicated by arrow R. The motor M may be oriented generally vertically, such that an axis of rotation of the motor M is arranged parallel to or coaxial with the fan axis X. However, other types of configurations are also contemplated. In operation, the motor M drives rotation of the fan 26 to move airflow through the fan and along a flow path, such as from a heat exchanger for example.

[0039] The fan 26 may include any number of fan blades 32. In the illustrated, non-limiting embodiment, the fan includes nine fan blades. However, it should be understood that

a fan 26 having any configuration including two or more blades is contemplated herein. The plurality of fan blades 32, may but need not be substantially identical.

[0040] With reference to FIG. 3, each fan blade 32 has a root 35 where the fan blade 32 meets and attaches to the hub 30 and a tip 36 at the outer extremity of the blade 32, opposite the root 35. The “span” of the fan blade 32 as referred to herein is intended to describe the distance between the root 35 and the tip 36. Each blade 32 additionally has a leading edge 38 located upstream with respect to a direction of rotation and a trailing edge 40 location downstream with respect to the direction of rotation. The leading and trailing edges 38, 40 are joined together at the root 35 and the tip 36. In the illustrated, non-limiting embodiment, the fan blades 32 are illustrated as having a sweep in the direction opposite the direction of fan rotation R, referred to as reverse or backward sweep. However, fan blades 32 having a sweep in the direction of the fan rotation, also referred to as forward sweep, and fan blades 32 having no sweep such that the tips 36 of the fan blades 32 are arranged generally within a plane are also contemplated herein.

[0041] FIG. 4 depicts a cross-sectional view of one of the plurality of fan blades 32, taken perpendicular to the radial axis of the fan blade 32. In the illustrated, non-limiting embodiment, each fan blade 32 has an airfoil or profile shaped cross-section 42 in which the leading edge 38 is curved in the rotating direction, so as to assume a convex shape, and the trailing edge 40 is curved so as to assume a convex shape in a direction away from the leading edge. A chord of the airfoil is a straight line extending between the leading and trailing edges of the airfoil. Similarly, a mean camber line, illustrates the asymmetry of the airfoil. The mean camber line is positioned halfway between the upper and lower surfaces 44, 46 of the airfoil.

[0042] With reference now to FIGS. 5-8, in an embodiment, the airfoil 42 of the fan blade 32 is configured to vary over at least a portion of the span of the fan blade 32. As a result of this variation, the fan blade 32 can have a non-uniform construction, for example a “wavy” construction. As used herein, the term “wavy” or “waves” can refer to undulations occurring in the span-wise direction, e.g., radial undulations occurring in successive concentric circular regions of the blade from the hub, undulations extending in a tangential direction directly linearly from leading edge to trailing edge, or undulations perpendicular a non-linear hub to tip profile, of a blade anywhere from the leading edge to the trailing edge. In any embodiment herein disclosed, such undulations can vary in amplitude as a function of one or more parameters of the blade 32, such as the chord of the blade. For example, at a corresponding radial position the blade can include lower amplitude waves (as measured in

the r-z plane in the attached figures) near the leading edge in comparison to waves at the trailing edge.

[0043] One or more of the parameters of the wavy fan blade 32 remain constant over the span of the blade 32. For example, the leading edge 38 of the fan blade 32 has a predetermined leading edge profile, and the position of the leading edge 38 at various locations over the span of the blade 32 is fixed to the desired profile. Alternatively, or in addition, the camber or asymmetry of the fan blade 32 may be generally fixed over the span of the blade.

[0044] In an embodiment, the chord of the airfoil 42 varies over at least part of the fan blade 32, such as the portion of the fan blade 32 generally adjacent the tip 36 for example. As the chord varies over all or a portion of the span of the fan blade 32, but the camber remains constant, one or more undulations, also referred to herein as “waves” 50, extending in a span wise direction are naturally formed in a surface of the fan blade 32. As best shown in FIGS. 7, 7A, and 7B, the angle of intersection of the camber and the chord adjacent the leading and trailing edges 36, 38 at each cross-section of the blade 32, illustrated schematically as θ , is configured to vary as the chord varies. However, because the camber of the blade 32 is held constant, the angle of intersection between the chord and the camber adjacent the leading edge 36, illustrated as θ_1 , remains constant between each cross-section. Similarly, the angle of intersection between the chord and the camber adjacent the trailing edge 38, illustrated as θ_2 , remains constant between each cross-section.

[0045] In an embodiment, the total number of waves 50 formed in the fan blade 32 is between two and six fan waves for example. For example, three waves are illustrated in the non-limiting embodiment shown in the FIGS. However, it should be understood that a fan blade 32 having any number of waves 50 formed therein is considered within the scope of the disclosure.

[0046] As previously suggested, the chord of the airfoil 42 may vary over only a portion of the span of the fan blade 32. Because the waves 50 are generated by this chord variation, the waves 50 are similarly formed over only the portion of the fan blade 32 where the chord varies. In an embodiment, the waves 50 are located at a position between 40% of the span and 100% of the span, or the blade tip 36. Accordingly, the one or more waves 50 are offset from the blade root 35. Further, the waves 50 are illustrated as being formed generally adjacent the trailing edge 40 of the fan blade 32. For example, the waves 50 may extend at a distance between 30%-100% of the chord, with 100% of the chord being located at the trailing edge 40. However, it should be understood that the embodiments where the

waves 50 are positioned adjacent the leading edge 38 are also within the scope of the disclosure.

[0047] The variation in the chord may be configured such that the waves 50 have a generally smooth contour i.e. without significant variations that result in a projection or unevenness. Alternatively, the variation in the chord may have a sharp, more angular contour, including an edge or point. The amplitude of the waves, measured parallel to the axis X of the fan may be generally constant, or alternatively, may vary. In an embodiment, the portion of the wave closest to the trailing edge 38 may have a greater amplitude than the portion of the wave closest to the leading edge 36. In yet another embodiment, the amplitude of the wave 50 may vary continuously between the leading and trailing edges 36,38.

[0048] In another embodiment, best shown in FIG. 7, one or more serrations 52 are formed along an edge, such as the trailing edge for example, of the fan blade 32. In an embodiment, the serrations 52 are formed as a result of the waves 50. For example, the serrations 52 may also occur when the camber of the fan blade 32 is held constant but the camber is varied over the span of the fan blade 32. Accordingly, the waves 50 and serrations 52 may be coupled such that each serration 52 corresponds to one or more of the waves 50.

[0049] The one or more serrations 52 extend in a chord wise direction and are similarly positioned between 40% and 100% of the span. The serrations 52 of the blade may be “cut away” from the nominal trailing edge of the blade, such that the chord at each of the serrations is less than at the nominal trailing edge. The nominal trailing edge is the imaginary trailing edge that would continue from the non-wavy section of the blade 32 to the tip 36 of the blade 32 if the blade 32 had no waves or serrations. Alternatively, the serrations 52 may extend beyond the nominal trailing edge of the blade 32, such that the chord at each of the serrations 52 is generally greater than at the nominal trailing edge. In the illustrated, non-limiting embodiment, three serrations are shown. However, a fan blade 32 having any number of serrations 52, such as one serration, between two and six serrations, or more than six serrations for example, is contemplated herein.

[0050] The serrations 52 may have a smooth contour, or alternatively, may have a sharp, more angular contour. In an embodiment, the serrations 52 have a saw tooth configuration with an amplitude between 0-30% of chord. The serrations 52 may be positioned directly adjacent one another such that no spacing exists between adjacent serrations 52. Alternatively, a gap or space may be positioned between adjacent serrations 52.

[0051] Inclusion of the waves and/or serrations generally adjacent the trailing edge of the fan blades creates phasing that provides a sound benefit over conventional fan blades. The waves 50 and/or serrations 52 may result in a reduction in noise between 3-6 decibels.

[0052] Embodiment 1: An axial flow fan comprising: a hub rotatable about a fan axis; a plurality of fan blades mounted to the hub, wherein one of the plurality of fan blades includes at least one wave extending in a span wise direction over the fan blade and at least one serration extending along a trailing edge of the fan blade, wherein the at least one wave and the at least one serration are arranged at a location between 40% and 100% of a span of the fan blade.

[0053] Embodiment 2: The axial flow fan of embodiment 1, wherein the at least one wave is positioned adjacent a trailing edge of the fan blade.

[0054] Embodiment 3: The axial flow fan of embodiment 2, wherein the at least one wave is arranged between 30% -100% of the chord as measured from a leading edge of the fan blade.

[0055] Embodiment 4: The axial flow fan of any of the preceding embodiments, wherein the at least one serration is formed in a chord of the fan blade.

[0056] Embodiment 5: The axial flow fan of any of the preceding embodiments, wherein a height of the at least one serration has is equal to between 0% and 30% of a chord length of the fan blade.

[0057] Embodiment 6: The axial flow fan of any of the preceding embodiments, wherein a contour of the at least one wave is generally smooth.

[0058] Embodiment 7: The axial flow fan of any of the preceding embodiments, wherein a contour of the at least one wave is generally sharp.

[0059] Embodiment 8: The axial flow fan of any of the preceding embodiments, wherein the at least one wave includes a plurality of waves.

[0060] Embodiment 9: The axial flow fan of embodiment 8, wherein the plurality of waves includes between two waves and six waves.

[0061] Embodiment 10: The axial flow fan of any of the preceding embodiments, wherein a contour of the at least one serration is generally smooth.

[0062] Embodiment 11: The axial flow fan of any of the preceding embodiments, wherein a contour of the at least one serration is generally sharp.

[0063] Embodiment 12: The axial flow fan of any of the preceding embodiments, wherein the at least one serration includes a plurality of serrations.

[0064] Embodiment 13: The axial flow fan of embodiment 12, wherein the plurality of waves includes between two serrations and six serrations.

[0065] Embodiment 14: The axial flow fan of any of the preceding embodiments, wherein the at least one wave is equal in number to the at least one serration.

[0066] Embodiment 15: The axial flow fan of any of the preceding embodiments, wherein a cross-section of the fan blade has a profiled airfoil shape.

[0067] Embodiment 16: The axial flow fan of any of the preceding embodiments, wherein the fan blade has a sweep.

[0068] Embodiment 17: The axial flow fan of any of the preceding embodiments, further comprising a shroud coupled to a tip end of each of the plurality of fan blades such that the shroud is rotatable about the fan axis.

[0069] Embodiment 18: The axial flow fan of any of the preceding embodiments, wherein the axial flow fan is formed from a plastic material via an injection molding process.

[0070] Embodiment 19: The axial flow fan of any of the preceding embodiments, wherein an amplitude of the one or more waves as measured along an axial dimension is larger at the trailing edge than at the leading edge.

[0071] Embodiment 20: The axial flow fan of any of the preceding embodiments, wherein an amplitude of the one or more waves as measured along the axial dimension varies continuously from the trailing edge than at the leading edge.

[0072] Embodiment 21: An axial flow fan comprising: a hub rotatable about a fan axis; a plurality of fan blades mounted to the hub; and a shroud mounted to a tip end of each of the plurality of fan blades; wherein each of the plurality of fan blades includes three waves extending in a span wise direction over the fan blade, the three waves being positioned adjacent a trailing edge of the fan blade between 40% and 100% of a span of the fan blade; and wherein each of the plurality of fan blades includes three serrations extending in a chord wise direction over the fan blade, the three serrations being positioned adjacent a trailing edge of the fan blade between 40% and 100% of a span of the fan blade.

[0073] While the present disclosure has been particularly shown and described with reference to the exemplary embodiments as illustrated in the drawing, it will be recognized by those skilled in the art that various modifications may be made without departing from the spirit and scope of the present disclosure. Therefore, it is intended that the present disclosure not be limited to the particular embodiment(s) disclosed as, but that the disclosure will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. An axial flow fan comprising:
a hub rotatable about a fan axis;
a plurality of fan blades mounted to the hub, wherein one of the plurality of fan blades includes at least one wave extending in a span wise direction over the fan blade and at least one serration extending along a trailing edge of the fan blade, wherein the at least one wave and the at least one serration are arranged at a location between 40% and 100% of a span of the fan blade.
2. The axial flow fan of claim 1, wherein the at least one wave is positioned adjacent a trailing edge of the fan blade.
3. The axial flow fan of claim 2, wherein the at least one wave is arranged between 30% -100% of the chord as measured from a leading edge of the fan blade.
4. The axial flow fan of any of the preceding claims, wherein the at least one serration is formed in a chord of the fan blade.
5. The axial flow fan of any of the preceding claims, wherein a height of the at least one serration has is equal to between 0% and 30% of a chord length of the fan blade.
6. The axial flow fan of any of the preceding claims, wherein a contour of the at least one wave is generally smooth.
7. The axial flow fan of any of the preceding claims, wherein a contour of the at least one wave is generally sharp.
8. The axial flow fan of any of the preceding claims, wherein the at least one wave includes a plurality of waves.
9. The axial flow fan of claim 8, wherein the plurality of waves includes between two waves and six waves.
10. The axial flow fan of any of the preceding claims, wherein a contour of the at least one serration is generally smooth.
11. The axial flow fan of any of the preceding claims, wherein a contour of the at least one serration is generally sharp.
12. The axial flow fan of any of the preceding claims, wherein the at least one serration includes a plurality of serrations.
13. The axial flow fan of claim 12, wherein the plurality of waves includes between two serrations and six serrations.
14. The axial flow fan of any of the preceding claims, wherein the at least one wave is equal in number to the at least one serration.

15. The axial flow fan of any of the preceding claims, wherein a cross-section of the fan blade has a profiled airfoil shape.

16. The axial flow fan of any of the preceding claims, wherein the fan blade has a sweep.

17. The axial flow fan of any of the preceding claims, further comprising a shroud coupled to a tip end of each of the plurality of fan blades such that the shroud is rotatable about the fan axis.

18. The axial flow fan of any of the preceding claims, wherein the axial flow fan is formed from a plastic material via an injection molding process.

19. The axial flow fan of any of the preceding claims, wherein an amplitude of the one or more waves as measured along an axial dimension is larger at the trailing edge than at the leading edge.

20. The axial flow fan of any of the preceding claims, wherein an amplitude of the one or more waves as measured along the axial dimension varies continuously from the trailing edge than at the leading edge.

21. An axial flow fan comprising:

a hub rotatable about a fan axis;

a plurality of fan blades mounted to the hub; and

a shroud mounted to a tip end of each of the plurality of fan blades;

wherein each of the plurality of fan blades includes three waves extending in a span wise direction over the fan blade, the three waves being positioned adjacent a trailing edge of the fan blade between 40% and 100% of a span of the fan blade; and

wherein each of the plurality of fan blades includes three serrations extending in a chord wise direction over the fan blade, the three serrations being positioned adjacent a trailing edge of the fan blade between 40% and 100% of a span of the fan blade.